SOLAR ACTIVITY AND TERRESTRIAL MAGNETIC DISTURBANCES.

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It has already been my privilege to lay before this society, on various occasions, some of the results obtained since 1905 of the magnetic survey work, chiefly of the oceans, conducted under the auspices of the Carnegie Institution of Washington. At the present rate of progress it seems reasonable to suppose that by the year 1915 it will be possible to construct a new set of magnetic charts as based upon homogeneous data largely obtained by one organization. Along with the magnetic survey of the oceans, begun on the "Galilee" in the Pacific Ocean in 1905 and continued until May, 1908, and now being conducted on the "Carnegie" in the Atlantic Ocean and later to be extended to the Indian Ocean, that of land areas is likewise in good progress, parties of the Carnegie Institution of Washington having already made notable expeditions in magnetically unexplored regions in all parts of the globe.

Provision has thus been made for a rapid and continuous accumulation of the data required for mapping the so-called "permanent" magnetic forces of the earth. As a matter of fact, however, the earth's magnetism is subject to continuous change, and owing to the so-called secular changes but a few years—five to ten—suffice to completely alter a chart showing the direction of the compass at various points over the globe. Hence, the work as being executed likewise embraces the determination of the secular changes in the earth's magnetism at a sufficient number of stations to permit applying the necessary corrections for keeping magnetic charts up to date.

However, there is another side to magnetic work, certainly not

less interesting, and possibly equally important to that mentioned—the investigation of the causes of those mysterious influences which daily, hourly, year in and year out, impress themselves upon the earth's magnetism. It is confidently believed by many that we must look primarily to the fluctuations of the delicately poised and sensitive magnetic needle for the key which will unlock the door to knowledge of the mysterious forces, coming from the regions beyond and conditioning the phenomena on which our welfare and development may, in no small measure, depend.

But aside from any such possible practical results, the belief is not without foundation that just as the great doctrine of evolution resulted from the persistent and searching inquiry into the causes producing the variations and mutations in biological phenomena, *our knowledge of the earth's magnetism is primarily to be advanced through the study of what causes the earth's magnetism to vary.* It also appears that when we shall have made an exhaustive study of the periodic magnetic variations, such as the solar-diurnal, the lunar-diurnal, the annual, etc., we shall find that none of these is strictly cyclic, but that each runs its course, through periods incommensurable with one another, the resulting residual effects at any moment of time being of sufficient magnitude to be reckoned with. Thus it may be possible to account for the secular variation of the earth's magnetism without resorting to any other cause than those daily in operation.

I shall now give a sketch of the chief results obtained along a line of inquiry being conducted coöperatively between two departments of the Carnegie Institution of Washington—the Solar Observatory at Mt. Wilson, California, under the direction of Professor George E. Hale and the Department of Research in Terrestrial Magnetism—viz., as to *the connection between solar activity and the earth's so-called magnetic storms.*

At an instant, without any previous warning, magnetic needles are caused to swing out of their usual position or direction, earth electric currents are generated of sufficient strength to interfere with telegraph and cable lines, brilliant and wide-spread auroras are evoked, and even electric car line traffic is momentarily suspended—by what? That is the problem. Possibly at the same time there

may be seen remarkable formations of sun-spots and the conclusion is drawn that there is some connection between the solar and terrestrial phenomena, especially so as similar coincidences have very often occurred in the past.

However, the connection is far from being such an immediately evident one. Many cases of magnetic storms might be cited when no sun-spots existed, at least on the face of the sun then visible. Then again, the area of a sun-spot is no true index either of the character or of the magnitude of a magnetic storm which may occur at about the same time. Thus one of the severest magnetic storms within the past fifty years—that of October 31 to November 1, 1903—was associated with a group of sun-spots considerably smaller than that in the earlier part of the month which was accompanied by a minor magnetic disturbance. Attempts at a direct connection between individual sun-spots and individual magnetic storms have not been wholly successful. While there have been a few cases—very few in fact—in which an apparently immediate connection was discovered between some striking solar phenomenon and a terrestrial magnetic fluctuation, there are vastly more instances for which no such individual relation existed. If, however, the subject is approached statistically, and the average state of the solar surface, as gauged by sun-spots or other eruptive phenomena, is compared with the average state of the earth's magnetism for a sufficient interval of time—a year or say several months—and these average values plotted, then a most striking resemblance is manifested between the two sets of phenomena. The parallelism, as intimated, is not so pronounced, however, for shorter intervals, for example that of a month.

The magnetic data generally used in such comparisons are the ranges or amplitudes of the daily fluctuations of the magnetic needle or say the frequencies of magnetic storms. During years of high sun-spot frequency, *i. e.*, increased solar activity, the diurnal swing of the needle is very appreciably greater than in years of low sun-spot frequency. And likewise without question the greatest number of, as well as generally the severest, magnetic storms occur in years of increased solar activity. While investigations exhibit a linear relationship between the average sun-spot frequencies and the

average diurnal range for a fairly long interval of time, so that one set of phenomena could be almost directly deduced from the other, a similar relation has not been found to hold between the *magnitude* of a magnetic disturbance and any measure of solar activity thus far proposed.

Fresh interest was shown in magnetic storms a year ago by Hale's discovery of magnetic fields in sun-spots and some persons immediately jumped to the conclusion that the origin of our magnetic storms had been discovered. However, the rapid decrease in the strength of the sun-spot fields with elevation, observed by Hale, shows that they, at the distance of the earth from the sun, could not by direct action produce an effect to be detected by the most sensitive modern magnetic apparatus, whereas the effects actually observed during a magnetic storm exceed by 100 and even 1,000 times the limit of measurement. It ought to be stated that Hale himself never, as far as I know, expressed any opinion as to the possibility of a direct magnetic action of sun-spots.

In order to pave the way towards a solution of some of the difficulties mentioned, the following investigation was originally begun, partly as the result of a desire on the part of Professor Hale to ascertain as quickly as possible what solar phenomena should be given chief attention in the proposed study. He wished to know, for example, how closely the curves resulting from his new method of measuring the solar activity—by the total area of the bright calcium flocculi seen on the sun's disc—corresponded with the well-known fluctuations in the earth's magnetic activity. He divided the sun's disc into zones 10° wide and determined the area of all the flocculi present in each zone. The sum of all the zones is the total area for the period in question and the solar activity was taken to be directly proportional to this area. Since the rotation period of the sun varies with solar latitude, means are taken for each zone corresponding to the rotation period for that zone in order to eliminate the effect of the solar rotation.

In my paper presented to the society a year ago I was enabled to communicate some preliminary results obtained from our comparative study of the variations in the sun's activity, as shown by the calcium flocculi measurements at the Mount Wilson Solar Observa-

tory for the period May, 1906, to January, 1909, and the variations in terrestrial magnetic activity during the same period, as based upon the observations at the five magnetic observatories of the U. S. Coast and Geodetic Survey. Probably the most important result then derived was that, in general, the earth's magnetization suffers a diminution during a period of intense solar activity. This pointed to the fact that the general, or average effect, of a magnetic storm was to superimpose on the earth's magnetization a system of magnetic forces equivalent to a demagnetizing system whose magnetic axis was reversed from that of the earth's magnetic field, so that the magnetic north pole of the disturbance system would lie in the southern hemisphere. While this relation between changes in solar activity and those in the earth's magnetism held, in general, for the period examined (May, 1906–January, 1909) there were some manifest contradictions also, so that for these an increase in solar activity corresponded to an increase in the earth's magnetization. These same contradictions were found to hold generally if we replaced Hale's measure of solar activity by the Wolfer curve of sun-spot frequency. There was thus again revealed the difficulty of establishing a relation which would link solar with magnetic phenomena in such a definite way that one set might be predicted from the other.

Additional discoveries regarding terrestrial magnetic disturbances may now be reported upon. A recent examination of the times of beginning of magnetic disturbances, as recorded at observatories over the entire globe, showed that, without doubt, magnetic storms do not begin at absolutely the same instant of time, as heretofore believed. Instead, they are found to progress over the earth in some definite manner and at a measurable speed. For the abrupt disturbances, which are usually comparatively minute in their effect on the compass needle, a complete passage around the earth would require from 3½ to 4 minutes. For the bigger effects, or for the larger magnetic storms, the differences of time between various stations are such that if these larger effects also traveled around the earth completely, it might take them a half hour or more. The following main conclusions were drawn:[2]

[2] *Journal Terrestrial Magnetism and Atmospheric Electricity,* Washington, D. C., Vol. 15, No. 1, March, 1910 (18 and 20).

It is thus seen that the disturbances of May 8, 1902, and of January 26, 1903, both traveled around the earth eastwardly, at an average velocity of about 6,700 miles per minute, taking from 3½ to 4 minutes to make the complete circuit. The disturbance of May 8, 1902, as determined from the times of beginning at the various stations, began in about the meridian of 75° west, whereas the initial meridian for the disturbance of January 26, 1903, computed in a similar manner, was found to be, roughly, 160° west. . . .

Magnetic storms do not begin at precisely the same instant all over the earth. The abruptly beginning ones, in which the effects are in general small, are propagated over the earth more often eastwardly though also at times westwardly, at a speed of about 7,000 miles per mnute, so that a complete circuit of the earth would be made in 3½ to 4 minutes. For the bigger and more complex magnetic disturbances the velocity of propagation may be cut down considerably. The time of beginning of the disturbance may be appreciably different, for the various magnetic elements, according to the character of the operating systems.

The moment it is granted that magnetic storms do not occur over the earth simultaneously, then a new point of view is presented for the investigation of the relation between magnetic storms and solar activity, and a definite criterion is set for testing any theory advanced. A second decisive test is furnished by another important fact disclosed by our study of the direction of motion of the two magnetic disturbances of May 8, 1902, and January 26, 1903. The electric currents which we should have to suppose circulating in the regions above us to produce the disturbance effects as actually recorded for the cases cited, would have to go around the earth eastwardly, if they are to be ascribed to a motion of negatively electrified particles. This is in fact the very direction in which the times of beginning of the disturbances were found to progress.

Were we to suppose now that magnetic disturbances are due to the entrance in the earth's magnetic field of small negatively electrified particles brought to us from the sun by the pressure of light, or were we to adopt the hypothesis of cathode rays coming from the sun, then, in either case, it would be found that the effect of the earth's magnetic field is to deflect these particles in such a way that, in the equatorial regions, for example, they would be made to circulate around the earth from east to west. But this direction is contrary to that in which we found the negative electric currents would have to go for the disturbances of May 8, 1902, and January 26, 1903, to harmonize with the times of beginning noted at stations

around the globe, and as shown to be necessary to account for the actual disturbance effects. Hence the direction test already excludes the possibility of ascribing certain of our magnetic storms, at least, to the effect of negatively electrified particles and cathode rays received from the sun. In a similar manner, it can be shown that positively electrified particles would likewise not accomplish the desired result.

But the time required for the quickest disturbances to get around the earth—about 3½ to 4 minutes—furnishes another crucial test. Knowing the electric charge carried by the particles, their velocity, and the deflecting effect of the earth's magnetism, it is possible to compute the radius of the circle around which they would have to move were they to come to the earth approximately, for example, in the plane of the equator and accomplish the circuit in 3¾ minutes. This radius turns out to be 580 times that of the earth's radius. Hence, these particles could never approach the earth closer than 2,300,000 miles! And if we compute the strength of the current necessary to produce at that distance even one of these comparatively minute magnetic disturbances, we find it would have to be on the order of 60,000,000 amperes, or sixty times that deemed sufficient to account for the big disturbances. We are accordingly forced to look elsewhere for the chief source of our magnetic storms. [The value of the radius, 2,300,000 miles above given applies to an electronic mass. Where we to increase the latter 1,000,000 times the radius would still be 23,000 miles. If we take the mass of the carrier of the electric charge the size of that of a particle brought to us by the pressure of light, the radius turns out less than that of the earth, hence an impossible result.]

In addition to negatively electrified particles coming from the sun, we also receive radiations such as the gamma rays of radium or the Röntgen rays, which are not deflected by the earth's magnetic field as they do not carry electric charges. Their chief effect would be to ionize the gases of which the atmosphere is composed, *i. e.*, make these gases better conductors of electricity. Ultra-violet light has the same effect. Now we know that a small part of the magnetic forces acting on a compass needle is due, not to magnetizations or electric currents below the earth's surface, but to electric

currents in the atmosphere. If then the regions of these upper electric currents are at any time made by some cause more conducting, electricity is immediately set in motion, which in turn induces a subsidiary magnetization in the earth. The effect then which we actually observe on the compass needle is the joint result of the newly generated electric currents in the atmosphere and the induced magnetization of the earth.

The direction followed by the new current depends upon its origin, upon the direction of the electromotive force of the primary electric field already existing at that point, and upon the deflecting effect of the earth's magnetic field and of the earth's rotation on the flowing current. *In other words, while we must doubtless look chiefly to extra-terrestrial agencies for the ionizing of the air and thus splitting it up into carriers of positive and of negative charges, we are compelled to look to the atmospheric electric field and to the earth's rotation for furnishing the energy necessary to drive the ions over the earth and by their motion produce the effects observed during a magnetic storm.*

We shall tentatively designate the theory which thus aims to account for terrestrial magnetic disturbance as "the ionic theory of magnetic disturbances." It is of interest to quote here from Schuster's extremely suggestive paper[3] on the "Diurnal Variation of Terrestrial Magnetism":

> Outbreaks of magnetic disturbances, affecting sometimes the whole of the earth simultaneously, may be explained by sudden local changes of conductivity which may extend through restricted or extensive portions of the atmosphere. I have shown in another place that the energy involved in a great magnetic storm is so considerable that we can only think of the earth's rotational energy as the source from which it ultimately is drawn. The earth can only act through its magnetization in combination with the circulation of the atmosphere, so that magnetic storms may be considered to be only highly magnified and sudden changes in the intensity of electric currents circulating under the action of electric forces which are always present.

How can we account, on the basis of the "ionic theory," for the velocity of motion of magnetic disturbances and, hence, for the time required to make a complete circuit of the earth? Starting from the well-established law as to motions of ions in gases, it is found that in

[3] *Phil. Trans. R. Soc., A,* Vol. 208, 1908, 184–185.

an electric field of one volt per centimeter (the average potential gradient found from atmospheric electricity observations on the surface), the velocity of the ions would at the height of about 75 kilometers or 47 miles be such that a complete circuit of the earth could be made in 3¾ minutes. Preliminary calculations show that at that height the existent electromotive force may be on the same order as actually assumed in the calculation. The height of 75 km. is about the average of that to which polar lights are seen. We thus place the electric currents, which may produce our magnetic disturbances, at a height where we know, from polar lights, electric currents actually exist.

Should the currents get lower down, then since their velocity varies inversely with atmospheric pressure, they will travel more slowly and the time required for a complete circuit of the earth is correspondingly increased. Their actual effect on a magnetic needle is, however, increased as they get nearer the surface. Hence we may say that the nearer a current gets to the earth's surface, the greater, in general, the disturbance effects and the slower the rate of propagation—this is in accordance, as we have seen, with actual observation. It seems probable that the reason for the remarkably large effects experienced during the magnetic disturbance of September 25, 1909, must be ascribed chiefly to the fact that the currents generated succeeded in getting closer to the earth than for the average magnetic storm.

It is thus seen that on the basis of the ionic theory of magnetic disturbances it is possible not only to explain, in a perfectly natural manner, why magnetic storms do not begin at absolutely the same instant of time over the earth, but also to account for the direction of propagation and the reason for the possible different rates of progression. Thus far, however, the examination has applied exclusively to the sudden beginnings of disturbances or to the simple disturbances characterized by Birkeland as "equatorial perturbations," which our analysis has shown to be chiefly due to a simple, uniform magnetic or electric system superposed upon the existing field. It seems probable that for this class of disturbances, the electric currents producing them are farthest away from us, *i. e.*, they are in the stratum of the atmosphere where their velocity is

such that a complete circuit of the earth, *if made,* would require from 3 to 4 minutes. In this connection it is worth while to record that, judging from Dr. van Bemmelen's observations at Batavia, Java, this interval of 3 to 4 minutes is also the average duration in general of the "starting impulse" at any one station.

After an interval of 3 or 4 minutes, the current either dies out or gets so far away as not to produce any effect. But it may also develop into a steady current continuing for an hour or more and then break out anew into a second starting impulse and finally develop into a complex current system with principal and secondary current vortices, as shown by the more complicated cases of magnetic disturbances.

Professor E. E. Barnard, a member of this society, has recently published[4] for the period 1902–09 a most valuable series of auroral observations made at the Yerkes Observatory from which we quote as follows:

> The streamers which spring from the arch as a base, and which always have a decided lateral motion and last for a minute or so only, almost always move to the west. On several occasions, however, I have seen them divide the arch, with respect to their motion, so that the ones to the west moved west and those to the east moved east. This is very rare. The motion is about 2° in one minute (and not 2 minutes to the degree as I stated in *Astrophysical Journal,* vol. 16, 143). I have wished to determine this motion more accurately, but we have had so few ray-producing auroras in late years, and the rays are so transient, that I have not been able to do so. It would be interesting to know if this motion is constant in a streamer and for all streamers.
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> The pulsating bright masses that usually appear in the northeast or northwest, but which are sometimes seen under the pole, are among the most interesting phenomena. They are sometimes present when there are no other evidences of an aurora.

If the motion of the streamers is at the rate of 2 degrees in one minute, it would take five to ten minutes or more for the motion to traverse a band from ten to twenty degrees wide. Now the possibility of such a slow motion is contrary to what the cathode ray theory with charged particles moving on the order of 60,000 miles a second would premise, but it is in strict accordance with the results announced regarding the non-simultaneity of magnetic disturbances and their rate of progression over the earth.

[4] *Astrophys. Jour.,* Chicago, Ill., Vol. 31, 1910, 208–233.

According to the theory of magnetic disturbances as set forth above, the various manifestations of solar activity with their resulting emanations and radiations are not the direct but the indirect cause of the earth's magnetic storms. Their effect appears to be more in the nature of a releasing or trigger action, setting in operation forces already in existence in the upper regions of the atmosphere; terrestrial sources, in reality, however, supply the energy required for a magnetic storm. To connect then the well-established, general relationship between magnetic disturbances and the sunspot period, we must suppose that the radiations which alter the conductivity of the atmosphere vary in their amount and intensity in accordance with the periodicity of the solar phenomena.

In the above theory of magnetic disturbances we had to depend on an already existing electric field. If we analyze the results of magnetic observations made at various points over the earth's surface, it is found that about 95 per cent. of the measured magnetic force can be accounted for by an internal magnetization of the earth or by an equivalent electric current system in its interior. The outstanding 5 per cent., however, can only be due to an electric field in the atmosphere.

A preliminary examination discloses the possibility that these atmospheric electric currents may be ascribed to Foucault, or eddy currents, induced in the more or less conducting layers of the atmosphere as, during its general circulation around the earth, the air currents are made to cut across the earth's lines of magnetic force.

The general atmospheric circulation consists in the main of two great atmospheric whirls, the one in the middle and higher latitudes of the northern hemisphere whirling around the north pole in a counter-clockwise direction supposing we are looking down on the north pole. A similar whirl exists in the southern hemisphere except that, if we could look down on the south pole we would see that the whirling is done in the clockwise direction. Could we, however, look at the two whirls in the same direction, for example, from the south pole to the north pole, then the motion would be in the same direction for both, viz., clockwise.

Between the two main whirls, which we shall designate as the "polar whirls," there is another—"the equatorial whirl"—the motion of which is anti-clockwise looking again from the south pole to the north pole the air currents (trade winds) blowing westwards. And, as known, on each border of the two sets of whirls, there exists a belt of high barometric pressure. The direction of motion of the air in the whirls is conditioned by the deflecting effect of the earth's rotation on the air-currents, which are primarily set in motion because of the temperature differences between the polar and the equatorial regions.

Considering first the polar whirls, since the air in them has a motion relative to that of the earth, having a greater velocity than that of the earth's rotation, the currents of air are made to cut across the lines of magnetic force, and that too in the regions of the earth where the most effective induction component—the vertical component of the magnetic force—is strongest. The electric currents thereby induced would, in general, follow a direction at right angles to the motion of the conducting air currents. Consulting a chart of the winds for various seasons, it is seen that the precise distribution of the induced electric currents will be rather complicated. In fact the determination of the exact course of Foucault currents is, in any case, not a simple matter. The displacement of the magnetic axis of the induced electric current system with reference to that of the earth, as dependent on the relative magnetic permeability of the two media involved, introduces another factor to be taken into account.

Since the equatorial atmospheric whirl is opposite to the polar ones, the Foucault negative currents, if brought about, would, generally speaking, be reversed and go around the earth in an opposite direction to the polar negative currents. But the equatorial currents cut the vertical component of the earth's magnetic force in regions of small vertical force, which in fact reduces to zero over the magnetic equator, hence they are considerably weaker than the polar ones. Their strength is further diminished by the fact that in the upper equatorial regions the whirl may be reversed (the anti-trades) and so there would be superposed on the surface equatorial electric currents a set of opposite electric currents.

Hence, as a first approximation, we may confine ourselves chiefly to the polar atmospheric electric currents. Owing to the direction in which they go—approximately southwest to northeast, if negative ones, and reverse for positive currents—it follows that their effect on a compass needle placed on the earth's surface is similar to that of the earth's own magnetism. Or, in other words, the magnetic system equivalent to the atmospheric electric system is precisely similar to that of the earth and the magnetic axis of the atmosphere is hence in the same general direction as the earth's.

There is this difference, however, between the two magnetic fields of the earth and of the atmosphere, viz., that while their north magnetic poles are both in the northern hemisphere, that of the earth is below the surface, whereas that of the atmosphere is in the regions above; hence, while the effects on the compass needle are the same for both, the effects on the dip needle are opposite. The earth's field makes the north-seeking end of the needle dip below the horizon in the northern magnetic hemisphere, whereas the magnetic field of the atmosphere, were it alone acting (the earth's field being eliminated) would make the north-seeking end of the needle point above the horizon. Hence the effects of the two fields on the vertical magnetic component are opposite in the same hemisphere.

In accordance with the well-known laws of induced magnetism or electricity, the atmospheric magnetic field would have to be related to the earth's own field in the following manner: First, the strength of the induced electric currents must be directly proportional to the earth's intensity of magnetization, the electrical conductivity of the atmospheric layers in which the currents flow, and the velocity of the air-currents; secondly, the magnetic axis of the atmospheric electric field must suffer a displacement with reference to the earth's magnetic axis in a direction opposite to that of the earth's rotation (since the earth is moving more slowly than the air-currents); hence, the atmosphere's north magnetic pole would have to lie west of that of the earth's. The angle of displacement depends upon the same quantities as did the strength of the currents, different functions, however, being involved; it cannot exceed 90°.

Examining the results to date from actual observations, a general agreement is found with the hypothesis—the electric currents in the atmosphere not only follow the general direction prescribed, but have a magnetic field whose axis is actually found displaced from that of the earth through an angle of 32° to the west and south. If we examine into the various effects of the primary electric field, many of the phenomena disclosed by the observations in atmospheric electricity, *e. g.*, relation to barometric changes, give additional support to the theory above set forth.

The mechanical effect of the currents induced in the atmosphere will be to increase the velocity of the earth's rotation or more likely to cause a displacement of the earth's magnetic axis eastward. We thus have introduced one of the several systems which together cause the secular variation of the earth's magnetism. This subject, as well as the conversion of electrical into thermal energy and the possible meteorological consequences thereof cannot be entered into here. So likewise mere reference can be made to the subject of the possible vertical earth-air electric currents, which the theory discloses and which I have already partially investigated. Thus far only the effects of the primary circulation of the atmosphere have been considered; manifestly there will be other effects from the secondary motions of the atmosphere.

If the primary atmospheric electric field is brought about electro-dynamically as explained, then it is reasonable to suppose that any periodic or spasmodic fluctuation in the general motions of the atmosphere will result in a corresponding change in the electric field, which in turn may give rise to a variation observed in terrestrial magnetism and atmospheric electricity. Now Schuster had previously shown that the diurnal variation of the earth's magnetism corresponded precisely to what would result from Foucault currents electro-dynamically induced by the daily oscillatory movements of the atmosphere with reference to the earth's lines of magnetic force. The motion of the air currents it was necessary to suppose for the production of the electric currents corresponded precisely to that as indicated by the diurnal oscillation of the barometer. To explain the difference of the effects on the magnetic needle between summer

and winter Schuster had to make the plausible hypothesis that the conductivity of the atmospheric regions was altered in the course of the year by the variation in the supply of the ionizing agencies coming from the sun. Schuster's currents are accordingly the diurnal variation of those of our primary atmospheric field on which we must depend, coupled with the earth's rotation, to furnish the actual supply of energy required to produce and maintain a magnetic storm.

The hypothesis above advanced for the formation of the primary atmospheric electric currents must, at present, be regarded as a tentative one. The precise determination of the characteristic features of this electric field cannot be attempted until the completion of the general magnetic survey of the globe. It ought to be pointed out, however, that the theory advanced to account for our magnetic disturbances is in no wise dependent upon the correctness of the hypothesis as to the origin of the primary electric field. While we do not know, at present, all we should like, we are sure of the existence of this field and that is all the theory requires.

In conclusion let me give you briefly another result obtained from our analysis of magnetic disturbances, viz., that as to the earth's magnetic permeability of which we have had thus far no knowledge. Taking the magnetic permeability of air as unity, it is found that for magnetizing forces on the order of 1/10,000 part of a C.G.S. unit, the earth's average magnetic permeability is about 2. The probabilities are that this value may be somewhat increased as the analysis progresses.